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Confounding factors affecting the marginal quality of an intra-oral scan

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ABSTRACT

Objectives: To assess the effect of clinical factors on the quality of intra-oral scans of crown margins. These factors are; presence of adjacent teeth, proximity to gingivae, encumbrance of wand positioning within oral cavity.

Methods: A typodont lower molar (Frasaco, Germany) was prepared for an all-ceramic crown with 1.5 mm supragingival (lingual) and equigingival (buccal) margins. The tooth was scanned in a model scanner, creating a master scan.

An intra-oral scanner (IOS) (Omnicam, Sirona Dental) was used to acquire sets of 5 scans each, under varying conditions; (1) the presence/absence of adjacent teeth, (2) model mounted in manikin head/hand-held, (3) with/without a 1 mm shim to elevate the margin. Every combination was investigated, yielding 40 scans (8 groups of 5).

The master scan margin was identified by selecting the highest curvature region (>1.8). The master was aligned to each IOS scan, and 4 regions of each IOS scan margin were extracted, lying within 100 μm of predefined mesial, distal, buccal and lingual sections of the master margin.

The mean curvature of each margin section was calculated using Meshlab. The effect of each confounding factor on margin curvature was analysed using ANOVA.

Results: Lingual margin curvature remained consistent regardless of scanning conditions. Buccal margin curvature was significantly affected when located equigingivally. Mesial margin curvature was significantly affected in the presence of adjacent teeth and proximity to the gingivae. Distal margin curvature was significantly affected by all three confounding factors.

Conclusions: The curvature (sharpness) of the margin recorded by a commercial IOS is significantly affected by clinical factors obscuring visibility.

1. Clinical significance

Intra-oral scanners require a direct line-of-sight when scanning crown margins. Common clinical factors (such as the presence of adjacent teeth, or encumbered wand positioning in the mouth) may prevent optimal scanning, causing inferior impressions. Clinicians should choose an appropriate impression technique (optical or traditional) based on assessment of these factors.

2. Introduction

A good impression for a fixed dental prosthesis should capture, among other things, the full margin of the preparation along with some unprepared tooth below the margin [1]. This ensures the technician can clearly identify the finishing margin and produce an appropriate emergence profile.

The quality of marginal fit is likely to be an important factor affecting the longevity of indirect restorations [2]. The susceptibility to leakage from a poorly fitting margin can lead to secondary caries or pulpal effects. The best measure by which marginal fit can be judged is not clear. Many workers use cross sections of replicas to quantify mean marginal gaps in 2-dimensions, generally providing up to 8 samples around the circumference of the tooth [3,4]. However, the maximum marginal gap has been suggested as the most clinically relevant measure [5], since this would likely form the point of failure of the marginal seal. The acceptable size of a marginal gap is also not clear, although values in the region of 100 μm have been suggested for conventional cements [6].

Since its inception over 30 years ago, intraoral scanning has become an increasingly popular method for recording impressions for dental prosthodontic treatment [7]. Much work has been reported comparing the trueness and precision of these scans to

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traditional impressions. In some cases comparisons are made between impressions of unprepared full dental arches [8–10]. In other works, the reproduction of individual crown preparations is assessed [3,4,11]. Modern intraoral scanners (IOSs) have a level of accuracy and precision comparable to, but not quite as good as, traditional techniques when recording full dental arches *in vivo* or *in vitro* [8–10]. In contrast, much of the work on individual crown preparations reports that IOSs produce crowns that are at least as accurate as those from scanned models of traditional physical impressions [12,13]. Much of this work is undertaken *in vitro* under ideal scanning conditions. Flugge [14] has shown that there is a deterioration in scan quality when using IOS's *in vivo*.

Whilst it seems true that IOSs are capable of recording accurate impressions of crown preparations under ideal conditions, the effect of common confounding factors on the quality of the digital impression has not been investigated.

In essence all IOS's require a direct line-of-sight on to any area they wish to record. If the local anatomy or morphology will not allow this, the area will not be recorded. Limitations to the line-of-sight may come from local anatomy (for example equigingival margins or adjacent teeth obscuring the view), or from more general confinements such as limited scanning wand positioning in the oral cavity. Less obviously, even if a line-of-sight is available, the quality of the scan may be affected by factors such as distance, angle of incidence and the arc of available viewing angles (the latter being the result of the 'quality assignment' that optical scanners apply to each scanned vertex, and the subsequent weighted averaging of all vertices within a small region). Therefore, assuming a region was visible from a restricted viewing angle, the operator will see that the scanner has captured the region and might assume that this area has been satisfactorily scanned. In reality, the quality of the scan in this region might be inferior due to the limited arc of visibility, or unfavourable wand orientation. Poor wand positioning is a major reason why IOS's have been shown to be technique sensitive [15]. Furthermore, limitations in wand positioning imposed by the structure and size of the oral cavity, the position and morphology of the tooth/preparation, and proximity to adjacent teeth may mean that it is sometimes not possible to achieve a line-of-sight to all areas of importance, despite the best clinical technique.

One metric by which the margin quality could be assessed is the 'curvature' of the margin. In computer graphics, each point in a 3D mesh is orientated (ie it is facing in a certain direction). The direction of orientation is called the 'normal', and the divergence of a points' normal, compared to its neighbours, is used to give a value of curvature at that point on the surface. High curvature values imply sharp edges whilst a curvature of zero means the surface is completely flat. Negative curvature values occur in concavities. Curvature is defined as the reciprocal of the radius of a sphere aligned to that 'patch' on a surface. Therefore, by definition a sphere with a radius of one has a curvature equal to one.

The curvature is used in many dental CAD packages to help locate the margin semi-automatically. Areas of lower curvature will require the user to make a guess as to where the margin should lie, adding imprecision to the procedure. These 'low curvature' regions can occur in areas where the scan quality is poor, or where the software has to interpolate and smooth the data (Fig. 1).

The aim of this study was to investigate the factors which may affect the curvature of the margin recorded in an intraoral scan of a lower left first molar. The factors investigated were:

1. The presence or absence of adjacent teeth.
2. The position of the margin relative to the gingivae.
3. The positional wand limitations imposed by the simulated oral cavity.

The effects of these confounding factors were investigated separately for margins located mesially, distally, lingually and buccally. The null hypothesis was that the marginal curvature of a single typodont all-ceramic preparation (36) will be the same, regardless of the confounding factors outlined above.

3. Materials and methods

A typodont lower left first molar (Model AG-3, Frasaco GmbH, Tettnang, Germany) was prepared for an all-ceramic eMax (lithium disilicate) crown, with a 1 mm shoulder margin, 2 mm occlusal reduction and an 8° taper. The lingual margin was positioned 1.5 mm supragingivally to act as a control throughout the experiment. The buccal margin was positioned equigingivally, while the approximal margins lay within 0.5 mm of the gingivae, moving more supragingivally as they went from buccal to lingual. The unprepared tooth below the mesial margin had a mesio-angular emergence profile whilst the tooth surface below the distal margin was relatively vertical (Fig. 2).

The single molar was scanned in a dental model scanner (Rexcan DS2, Europac 3D, Crewe, UK) which has a trueness and precision of $<10\,\mu m$. The STL file was imported into Meshlab (http://meshlab.sourceforge.net/) and the pseudo inverse quadric curvature filter was applied using the default settings, to calculate the curvature at all vertices on the mesh. Next, the margin was selected by choosing all vertices with a curvature greater than 1.8 (Fig. 2). The margin was then further subdivided manually into four regions representing the mesial, distal, buccal and lingual zones (Fig. 2). These four margin sections were saved for use as the master templates.

The prepared tooth was placed in a Frasaco jaw model. Throughout the following experiments, a single experienced

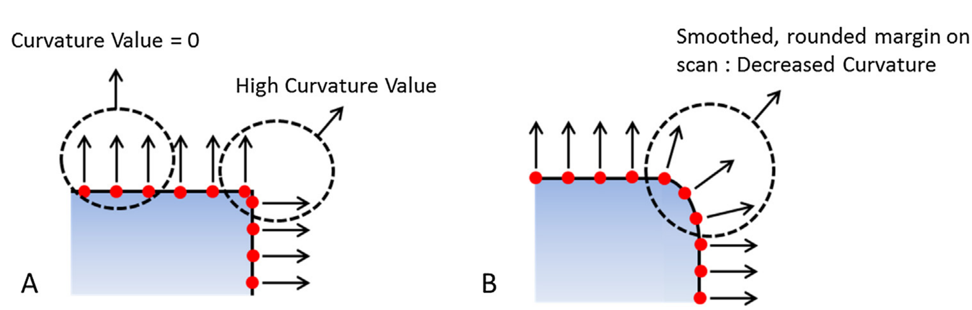

Fig. 1. The Curvature of a Margin. A good scan of a well-defined shoulder margin is shown (A). The 3D points (red) are orientated in the direction of the underlying surface (black arrows). Flat regions have zero curvature because the angle between adjacent points is zero. The sharp shoulder margin has a high curvature because the angle between adjacent points is high. A poor scan of the same shoulder is shown in (B). Here, the software has 'smoothed' the shoulder due to missing data in the scan. The value of the curvature at the margin will be decreased, and this serves as a measure of the quality of the scan at the margin. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)